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MULTI-RESPONSE OPTIMISATION OF MACHINING PARAMETERS IN TURNING AISI 304L USING DIFFERENT OIL-BASED CUTTING FLUIDS

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ABSTRACT

Properties of melon seed and beniseed oils which are considered as "environmentally" friendly oils were investigated and the performance evaluation of the formulated beniseed and melon seed oil-based cutting fluids were carried out. American Iron and Steel Institute (AISI) 304L alloy steel was used as workpiece and tungsten carbide as cutting tool, while commercial mineral oil- based cutting fluid was used as a control experiment. The viscosities of the melon seed oil and beniseed oil- based cutting fluids were 1.53 $mm^{2/s}$ and 0.86$mm^{2/}$s, while their pH values were 8.2 and 8.7 respectively. The optimal multi-response turning parameters was achieved using cutting speed of 159 rev/min (level 3), feed rate of 0.9 mm/rev (level 3), depth of cut of 1 mm (level 2) and type of cutting fluid of 1.53mm/s (level 3). The ANOVA results show that feed rate has the most significant effect on the surface roughness (92.93%) and cutting temperature (27.51%).

Keywords*: Cutting fluids; Surface roughness; Temperature; Cutting tool.*

1. INTRODUCTION

Metal cutting process form the foundation of the engineering industry and is involved either indirectly or directly in the manufacture of nearly every product of our modern civilization [1]. Metal cutting is associated with high temperatures which strongly affect the accuracy of the machining operation [2]. The high forces in machining create a considerable amount of heat near the cutting edge. Most of this heat is generated within the shearing process and some heat is created by friction between the tool and workpiece. Much of the generated heat is carried off in the chips, while the remainder stays in the tool and workpiece, creating a large amount of thermal stress and softening of the cutting tool. This causes wear on the cutting edge of the tool thereby increasing the surface roughness of the sample. To minimise the adverse effect of the high temperatures, cutting fluid (coolant) is often used to bathe the tool and workpiece to reduce much of the heat and limit damage to the tool and workpiece. The three major cutting parameters in turning operation are the cutting speed, feed rate and depth of cut, these parameters need to be properly determined to achieve high performance result [3]. These cutting parameters are reflected on surface roughness, surface texture and dimensional deviations of the product [4]. Most of these cutting fluids in use presently are of mineral oil origin. However, they are environmentally unfriendly, costly, potentially toxic and with health challenges [5]. A shift to dry cutting has not completely solved the problem [6]. Hill [7] investigated the use of fats and oils as oleochemical raw materials and noted that there is tremendous increase of approximately 3% yearly in the production of oils and fats from plants and animals. It was predicted that this trend of oils and fats production from plant and animals will continue in the medium and long terms.

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Hwang and Lee [8] investigated minimum quantity lubrication and wet turning process of AISI 1045 workpiece material with the objective of determining the experimental model to predict the cutting force and surface roughness, with a view to selecting the optimal cutting parameters and to analysing the effect of cutting parameters on machinability. Result of the experiment showed that cutting speed and depth of cut had opposite effects on cutting force and surface roughness. Also, Lawal et al [9] evaluated the influence of cutting fluids on flank wear during turning of AISI 4340 alloy steel with coated carbide inserts. The performances of three types of cutting fluids were compared using Taguchi method. The effect of palm kernel oil- based emulsion cutting fluid, cotton seed oil- based emulsion cutting fluid and mineral oil- based emulsion cutting fluids on flank wear during turning of AISI 4340 alloy steel with coated carbide inserts were investigated. The result showed the optimal cutting parameters for the flank wear using signal to noise ratio as: 160 m/min of cutting speed, 0.18 mm/rev of feed, 1.75 mm depth of cut and 2.97 mm^2/s flow rate for palm kernel oil-based cutting fluid. Analysis of variance showed cutting speed (85.36%) and feed rate (4.81%) as significant factors that affects flank wear, while depth of cut (2.5%) and cutting fluid (1.8%) were the insignificant factors. Bajic and majce [10] also investigated the influence of cutting parameters on the surface roughness, during the longitudinal turning process. It was reported that the increase of the cutting speed in a certain interval affected the improvement of the surface roughness. The feed has the greatest impact on the surface roughness such that the more it decreased, the more it improved the surface roughness and the increase of depth of cut improved the surface roughness as well, which can be taken as an advantage for the improvement in productivity.

Onuoha [11] also investigated the suitability of vegetable-based oils in orthogonal machining of 1330 carbon steel using Taguchi method. Machining of medium carbon steel AISI 1330 carbon steel was carried out with high speed steel (HSS) cutting tool using the formulated cutting fluids to ascertain their performance as compared with the conventional mineral oil- based cutting fluid. The experimental results showed that feed rate had the most significant effect on the surface roughness while cutting speed had the most significant effect (66.54%) on cutting temperature. Yu et al [12] also formulated a cutting fluid using castor acid, castor oil and soybean oil. The experimental results indicated that the cutting fluids had good cooling, cleaning, anti-rust, anti-corrosive and lubricating properties, as well as having stable and reliable quality, long service life, easily available raw materials and low production cost.

Yivo et al [13] reported that grey relational analysis (GRA) optimisation procedure is a multi-response optimization technique which involves combining all performance characteristics into a particular value which can be utilised as the single characteristic in optimisation problems. Therefore, in this study, a coated carbide tool was used to evaluate the performance of melon seed and beniseed oil- based cutting fluids, compared to mineral oil- based cutting fluid, when machining AISI 304L austenitic stainless steel alloy workpiece.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Cutting Fluid Formulation

The materials used in this study for the formulation of the cutting fluid include melon seed oil, beniseed oil and mineral soluble oil (MobilMet 424). Other additives used include emulsifier (0.5M sodium lauryl sulphate + sodium tripolyphospate + sulphonic acid + calcium carbonate in 5litres of water), banana plant juice (anti-corrosion agent) and biocide

2.1.2 Workpiece, cutting tool and equipment

The materials used for the machining processes include TNMG 1604 tungsten carbide insert cutting tool, 4-jaw lathe and an AISI 304L stainless steel.

2.2 Methods

2.2.1 Physicochemical Properties and Fatty Acid Composition

The physicochemical properties of the melon seed and beniseed oils were analyzed using standard testing procedure such ASTM D445, ASTM D93 and ASTM D4052 while determination of fatty acid composition was conducted using a gas chromatograph [Mass spectrometer (GC-MS) instrument GC-MS-QP2010 Shimadzu system, Japan] with the following conditions employed: Column over temperature of 70.0°C; injection temperature of 250.0°C; Column flow was 1.80mL/min with total flow of 40.8mL/min at linear velocity of 49.2cm/sec and pressure of 116.9kpa.

2.2.2 Formulation of Emulsion Cutting Fluid

The preparation of cutting fluid was based on the method adopted by Muniz et al [14]. This procedure involved controlled addition of additives to the oil using a magnetic stirrer (Hotplate 79-1). The percentage ratios of additives used were 9.35% emulsifier, 0.97% biocide, 10.61% anticorrosive agent, 0.64% antioxidant [11]. However, the formulation of mineral based cutting fluid involved mixing the soluble oil (concentrate) with water at the ratio of 1: 9.

2.2.3 Characterization of Formulated Cutting Fluids

The formulated cutting fluids were characterized to determine the pH value, viscosity, corrosion level and stability. The pH values were measured with pH meter while viscosity was determined using ASTM D445 measurement procedure. The corrosion level was determined using the test method adopted by [15], while the stability was evaluated using a visual transparency within a period of 24hours at room temperature as to the separation of water and oil in a graduated 1000 ml test tubes.

2.2.4 Design of Experiment

DOE was carried out in accordance with full factorial $L_{81}(3)^4$ design technique using Minitab 17 statistical software. The factor levels of input variables are shown in Table 1 while the experimental design layout is shown in Table 2.

Table 1: Factor Levels of Machining Variables

Factor	Unit	Level 1 (-)	Level 2 (0)	Level 3 (+)
Cutting Speed	rev/min	93	126	159
Feed Rate	mm/rev	0.5	0.7	0.9
Depth of Cut	Mm	0.8	1.0	1.2
Types of Cutting Fluids	mm^2/s	MSO	BSO	CMO

MSO (Melon seed oil); CMO (Commercial mineral oil) and BSO (Beniseed oil)

2.2.5 Machining Process

Turning operation was conducted on a 4-jaw conventional lathe (MITCHELL of Keighley, variable spindle speed: 30-400rpm and 5Hp rated power). A triangular tungsten carbide tool inserts (TNMG 1604, Canela Tools) was used with a new cutting edge for each experiment. The investigation of surface roughness and cutting temperature were conducted on stainless steel (AISI 304L) round bars of 80mm diameter by 320mm length to achieve a ratio of diameter to length of 1:4 which ensures rigidity and eliminates flexing during the turning operation [16]. Each test specimen was mounted on the lathe between the chuck and the live centre to ensure greater clamping force during turning. A thin outer surface of each specimen was machined off before the start of the experiments for uniformity. The workpiece was afterward turned at different depths, turning speeds and feed rates as specified in Table 2.

Table 2: Full Factorial $L_{81}(3)^4$ Experimental Design Layout

Run Order	Cutting Speed	Feed Rate	Depth of Cut	Type of Cutting Fluids
1	93	0.5	0.8	MSO
2	93	0.9	1.2	CMO
3	159	0.9	0.8	MSO
4	159	0.7	0.8	BSO
5	159	0.9	1	CMO
6	126	0.9	1.2	CMO
7	126	0.7	0.8	CMO
8	126	0.9	0.8	CMO
9	126	0.7	0.8	MSO
10	159	0.5	1.2	CMO
11	159	0.5	1	CMO
12	159	0.5	0.8	BSO
13	93	0.9	1	MSO
14	126	0.7	1.2	CMO
15	93	0.7	0.8	MSO
16	93	0.7	1.2	BSO
17	93	0.7	1.2	MSO
18	93	0.5	1.2	BSO
19	93	0.5	0.8	BSO
20	126	0.9	0.8	MSO
21	159	0.7	1.2	BSO
22	159	0.9	1	MSO
23	126	0.9	1	MSO
24	93	0.7	1.2	CMO
25	159	0.9	1.2	BSO
26	93	0.7	0.8	CMO
27	159	0.9	1.2	MSO
28	126	0.5	1.2	BSO
29	159	0.7	1	MSO
30	159	0.9	0.8	BSO
31	126	0.5	1.2	MSO
32	159	0.7	1.2	CMO
33	159	0.7	1	CMO
34	93	0.9	1	CMO
35	126	0.5	1	MSO
36	126	0.7	1	MSO
37	159	0.5	0.8	CMO
38	159	0.9	1.2	CMO
39	93	0.9	0.8	CMO
40	159	0.5	1	BSO
41	126	0.7	0.8	BSO
42	126	0.9	1.2	MSO
43	93	0.7	1	BSO
44	93	0.9	0.8	BSO

Run Order	Cutting Speed	Feed Rate	Depth of Cut	Type of Cutting Fluids
45	93	0.9	1.2	BSO
46	159	0.7	0.8	CMO
47	126	0.5	1.2	CMO
48	159	0.5	1.2	BSO
49	93	0.5	1	BSO
50	93	0.7	0.8	BSO
51	126	0.9	1.2	BSO
52	126	0.9	0.8	BSO
53	126	0.9	1	BSO
54	159	0.7	1	BSO
55	126	0.5	1	BSO
56	93	0.9	1	BSO
57	159	0.9	1	BSO
58	126	0.7	1.2	MSO
59	93	0.5	0.8	CMO
60	93	0.5	1.2	CMO
61	126	0.9	1	CMO
62	93	0.5	1	MSO
63	126	0.7	1	BSO
64	93	0.7	1	CMO
65	126	0.7	1.2	BSO
66	93	0.7	1	MSO
67	159	0.5	1.2	MSO
68	159	0.7	0.8	MSO
69	159	0.5	1	MSO
70	159	0.7	1.2	MSO
71	159	0.5	0.8	MSO
72	126	0.5	1	CMO
73	126	0.5	0.8	MSO
74	126	0.5	0.8	CMO
75	126	0.7	1	CMO
76	126	0.5	0.8	BSO
77	159	0.9	0.8	CMO
78	93	0.9	1.2	MSO
79	93	0.9	0.8	MSO
80	93	0.5	1.2	MSO
81	93	0.5	1	CMO

2.2.6 Surface Roughness Measurement

Surface integrity of each machined portion of the workpiece were measured using Surface Roughness Tester (Model: STR-6210S, GuangZhouLandtek) at three locations around the circumference of the round bar workpiece and the average of these reading recorded for each experiment.

2.2.7 Cutting Temperature Measurement

The highest cutting temperature during each experimental run was measured using a Contact Digital Thermometer (Model: TP300, range: -50 to 300°C). Each experimental run was timed for a period of 10 minutes using Casio G-Shock digital stop watch.

3. RESULTS AND DISCUSSIONS

3.1 Physicochemical Characterization

The results of the physicochemical properties of melon seed oil (MSO) and beniseed oil (BSO) are presented in Table 3.

From the results in Table 3, it can be confirmed that the properties of melon and beniseed oils can be used for cutting fluids as the values are within the range, however with addition of additives and this is in agreement with the earlier report [17]. The low density exhibited by both oils indicates that they are lighter than water while the low cloud and pour points of oils signifies a better pumping property at relatively low temperatures. The flash points of both oils (melon and beniseed) are 315°C and 285°C respectively, which make them safe for use as lubricants while the pH values of the melon and beniseed oils are 3.62 and 5.28 respectively, which show that both are acidic. The acidity of oil provides a reference point for monitoring oil condition during use; as an increase in acidity during use indicates the accumulation of oxidation products in the oil [18].

Table 3: Physicochemical Properties of Melon Seed and Beniseed Oils

S/N	Parameter	Value (melon seed)	Value (beniseed)
1	Specific Gravity	0.913	0.902
2	Acid Value mg KOH/g	9.39	3.08
3	Free Fatty Acid mg KOH/g	18.79	6.17
4	Saponification Value mg/g	189.34	217.38
5	Viscosity mm^2s^{-1} @ 40°C	9.38	11.96
6	Iodine Value g/100g	82.90	59.17
7	Moisture Content %	3.87	2.13
8	pH	3.62	5.28
9	Flash Point °C	315	285
10	Cloud Point °C	-8	-6
11	Pour Point °C	-3	-3

3.2 Fatty Acid Composition

The results of gas chromatograph -mass spectrometer (GC-MS) analysis of the melon seed and beniseed oils are presented in Fig. 1 and 2. Interpretation of mass spectrum GC-MS was done using the database of National Institute of Standard and Technology (NIST), having more than 62,000 patterns in the Library that is built into the GC-MS machine.

Tables 4 shows the fatty acid composition results of MSO and BSO. From the results, oleic acid (mono-unsaturated acid) has the highest values of 54.08% and 48.11% respectively for both MSO and BSO. Hence, the two oils can be classified as unsaturated.

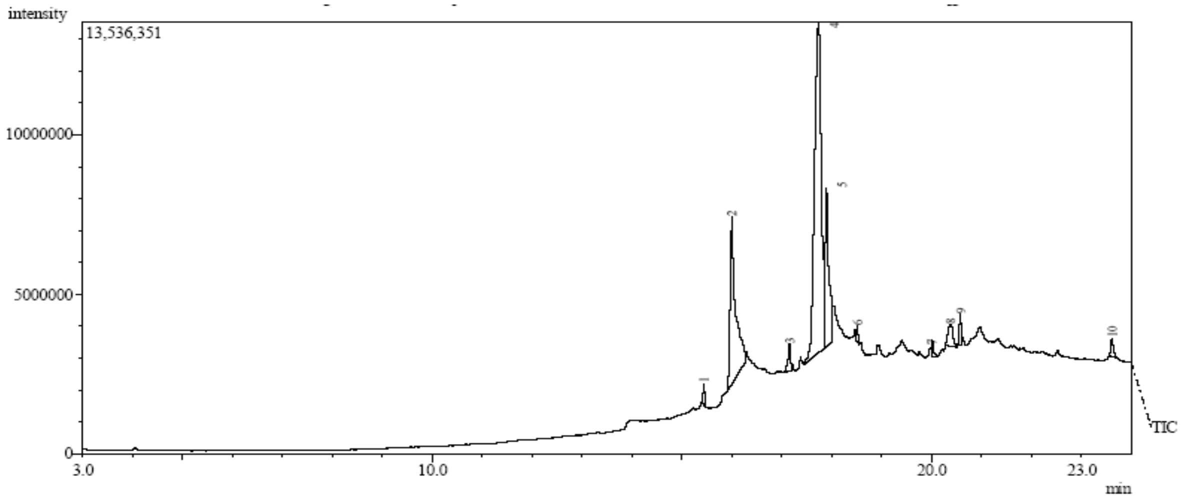

Fig. 1: GC-MS Chromatogram of MSO

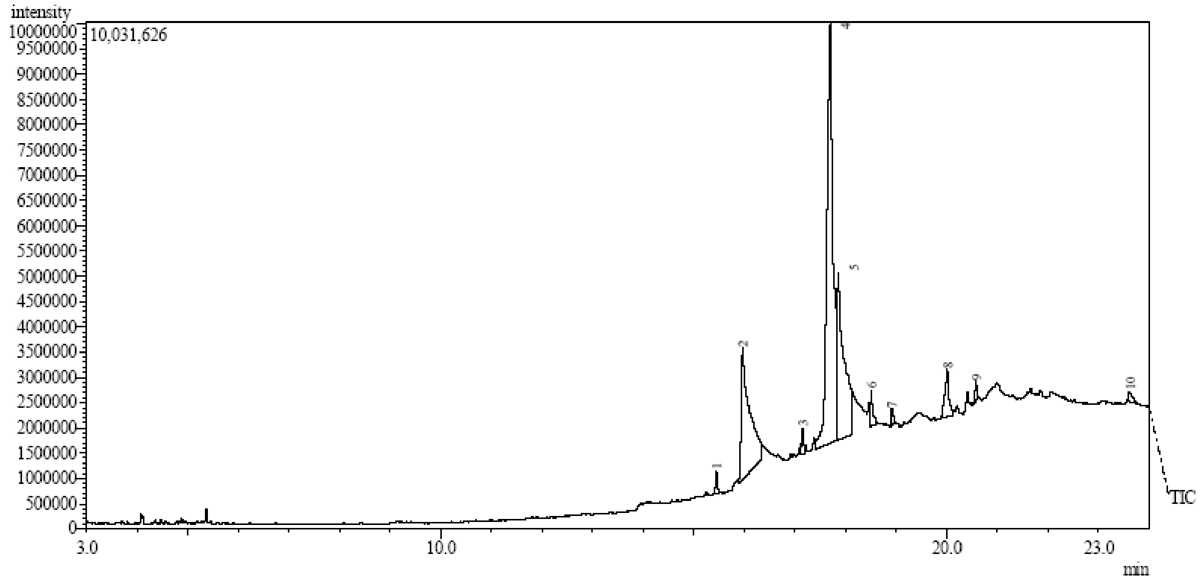

Fig. 2: GC-MS Chromatogram of BSO

Table 4: Fatty Acid Composition of MSO and BSO

Peaks	Retention Time (min)		Compound	Chemical Formula		Molecular Weight (g/mol)		% Area	
	MSO	BSO		MSO	BSO	MSO	BSO	MSO	BSO
1	15.442	15.450	Pentadecanoic Acid	$C_{17}H_{34}O_2$	$C_{17}H_{34}O_2$	270	270	0.76	0.83
2	16.001	15.971	Palmitic Acid	$C_{16}H_{32}O_2$	$C_{16}H_{32}O_2$	256	256	21.99	20.02
3	17.154	17.159	Elaidic Acid	$C_{19}H_{36}O_2$	$C_{19}H_{36}O_2$	296	296	1.71	0.87
4	17.747	17.697	Oleic Acid	$C_{18}H_{34}O_2$	$C_{18}H_{34}O_2$	282	282	54.08	48.11
5	17.899	17.860	Stearic Acid	$C_{18}H_{36}O_2$	$C_{18}H_{36}O_2$	284	284	14.93	22.43
6	18.515	18.514	1-Nonadecanol	$C_{19}H_{40}O$	$C_9H_{16}BrNO$	284	233	0.63	1.75
7	20.017	18.915	Linolenic Acid	$C_{20}H_{34}O_2$	$C_{12}H_{26}O$	306	186	0.76	0.66
8	20.388	20.019	5-Cholestene-3ol	$C_{28}H_{48}O$	$C_{14}H_{26}O$	400	210	2.49	3.78
9	20.576	20.580	13-Docosenoic Acid methyl ether	$C_{23}H_{44}O_2$	$C_{23}H_{44}O_2$	352	352	1.51	0.77
10	23.609	23.616	Squalene	$C_{30}H_{50}$	$C_{30}H_{50}$	410	410	1.13	0.78
								100	100

3.3 Characterization of Cutting Fluids

The characteristics of the formulated and commercially available (CMO) oil-in-water emulsion cutting fluids used in this study are shown in Table 5.

Table 5: Characteristics of cutting fluids

S/N	Property	Melon Seed (MSO)	Beniseed (BSO)	Mineral oil (CMO)
1	Viscosity (η) (mm²/s)	1.53	0.86	1.00
2	pH Value	8.2	8.7	8.9
3	Corrosion Level	Corrosion Resistant	Corrosion Resistant	Corrosion Resistant
4	Stability	Stable	Stable	Stable
5	Colour	Milky	Milky	Milky

The results shown in Table 5 indicates that the MSO, BSO and CMO are stable, milky and non-corrosive cutting fluids with viscosity of 1.53, 0.86 and 1 (mm²/s) respectively, thereby making it effective and safe-to use

3.4 Experimental Results and S/N Ratios

The results of the experiment carried out using the experimental design layout along with their respective signal-to noise (S/N) ratio values are shown in Table 6. It can be observed that the value of responses (temperature and surface roughness) changes with variation in the process parameters.

Signal-to noise (S/N) ratios of individual responses were calculated using Equ. 1 and 2.

Smaller-the better:

$$\text{S/N}= -10\log\frac{1}{n}\left(\sum\nolimits_{i-1}^{n} y_i^2\right) \qquad (1)$$

Larger-the better:

$$\text{S/N} = -10\log\frac{1}{n}\left(\sum\nolimits_{i-1}^{n}\frac{1}{y_i^2}\right) \qquad (2)$$

where S/N is signal to noise ratio, n is the number of repetition in a trial and y is the measure quality characteristic for the ith repetition

Table 6: Experimental process parameters, response values and S/N ratios

Run Order	Cutting Speed CS (rev/min)	Feed Rate FR (mm/rev)	Depth of Cut DOC (mm)	Type of Cutting Fluids (TCF) (η) (mm²/s)	Surface Roughness Ra (μm)	S/N ratio for Surface Roughness (db)	Temperature T (°C)	S/N ratio for Temperature (db)
1	93	0.5	0.8	1.53	1.10	-0.83	40.9	-32.23
2	93	0.9	1.2	1	7.76	-17.80	57.2	-35.15
3	159	0.9	0.8	1.53	9.49	-19.55	59.7	-35.52
4	159	0.7	0.8	0.86	3.44	-10.73	50.1	-34.00
5	159	0.9	1	1	10.13	-20.11	67.1	-36.53
6	126	0.9	1.2	1	8.84	-18.93	60.5	-35.64
7	126	0.7	0.8	1	1.83	-5.25	50.3	-34.03
8	126	0.9	0.8	1	6.67	-16.48	52.4	-34.39
9	126	0.7	0.8	1.53	3.52	-10.93	39.7	-31.98
10	159	0.5	1.2	1	2.53	-8.06	54.8	-34.78
11	159	0.5	1	1	1.97	-5.89	51.6	-34.25
12	159	0.5	0.8	0.86	2.56	-8.16	43.4	-32.75
13	93	0.9	1	1.53	8.74	-18.83	50.5	-34.07
14	126	0.7	1.2	1	1.92	-5.67	61.1	-35.72
15	93	0.7	0.8	1.53	2.86	-9.13	44.6	-32.99
16	93	0.7	1.2	0.86	6.42	-16.15	56.4	-35.03
17	93	0.7	1.2	1.53	2.47	-7.85	44.3	-32.93
18	93	0.5	1.2	0.86	2.03	-6.15	56.9	-35.10
19	93	0.5	0.8	0.86	1.97	-5.89	50.6	-34.08
20	126	0.9	0.8	1.53	8.90	-18.99	41.6	-32.38
21	159	0.7	1.2	0.86	2.23	-6.97	52.5	-34.40
22	159	0.9	1	1.53	8.17	-18.24	80.2	-38.08
23	126	0.9	1	1.53	8.89	-18.98	41.0	-32.26
24	93	0.7	1.2	1	2.96	-9.43	67.7	-36.61
25	159	0.9	1.2	0.86	7.74	-17.77	58.7	-35.37
26	93	0.7	0.8	1	2.34	-7.38	58.2	-35.30
27	159	0.9	1.2	1.53	9.05	-19.13	87.0	-38.79
28	126	0.5	1.2	0.86	1.55	-3.81	55.7	-34.92
29	159	0.7	1	1.53	2.71	-8.66	60.3	-35.61
30	159	0.9	0.8	0.86	7.35	-17.33	48.0	-33.62
31	126	0.5	1.2	1.53	3..31	-10.40	46.1	-33.27
32	159	0.7	1.2	1	3.15	-9.97	61.2	-35.74
33	159	0.7	1	1	2.70	-8.63	59.1	-35.43
34	93	0.9	1	1	8.67	-18.76	53.3	-34.53
35	126	0.5	1	1.53	1.57	-3.92	40.2	-32.08

Run Order	Cutting Speed CS (rev/min)	Feed Rate FR (mm/rev)	Depth of Cut DOC (mm)	Type of Cutting Fluids (TCF) (η) (mm^2/s)	Surface Roughness Ra (μm)	S/N ratio for Surface Roughness (db)	Temperature T (^{o}C)	S/N ratio for Temperature (db)
36	126	0.7	1	1.53	1.98	-5.93	43.8	-32.83
37	159	0.5	0.8	1	1.58	-3.97	48.9	-33.79
38	159	0.9	1.2	1	10.01	-20.01	73.1	-37.28
39	93	0.9	0.8	1	8.41	-18.50	69.2	-36.80
40	159	0.5	1	0.86	2.11	-6.49	45.9	-33.24
41	126	0.7	0.8	0.86	2.84	-9.07	48.8	-33.77
42	126	0.9	1.2	1.53	9.69	-19.73	47.8	-33.59
43	93	0.7	1	0.86	5.85	-15.34	53.2	-34.52
44	93	0.9	0.8	0.86	8.56	-18.65	49.7	-33.93
45	93	0.9	1.2	0.86	8.65	-18.74	58.1	-35.28
46	159	0.7	0.8	1	2.35	-7.42	55.2	-34.84
47	126	0.5	1.2	1	2.76	-8.82	70.0	-36.90
48	159	0.5	1.2	0.86	1.54	-3.75	45.1	-33.08
49	93	0.5	1	0.86	2.09	-6.40	52.4	-34.39
50	93	0.7	0.8	0.86	2.74	-8.76	50.7	-34.10
51	126	0.9	1.2	0.86	7.70	-17.73	54.5	-34.73
52	126	0.9	0.8	0.86	8.39	-18.48	48.0	-33.62
53	126	0.9	1	0.86	9.42	-19.48	50.8	-34.12
54	159	0.7	1	0.86	3.69	-11.34	50.0	-33.98
55	126	0.5	1	0.86	1.64	-4.30	52.5	-34.40
56	93	0.9	1	0.86	8.26	-18.34	54.4	-34.71
57	159	0.9	1	0.86	9.49	-19.55	51.6	-34.25
58	126	0.7	1.2	1.53	3.72	-11.41	45.2	-33.10
59	93	0.5	0.8	1	1.46	-3.29	48.7	-33.75
60	93	0.5	1.2	1	1.62	-4.19	46.8	-33.40
61	126	0.9	1	1	8.13	-18.20	57.2	-35.15
62	93	0.5	1	1.53	1.32	-2.41	41.5	-32.36
63	126	0.7	1	0.86	1.91	-5.62	55.2	-34.84
64	93	0.7	1	1	1.94	-5.76	64.8	-36.23
65	126	0.7	1.2	0.86	2.56	-8.16	60.2	-35.59
66	93	0.7	1	1.53	3.7	-11.36	48.2	-33.66
67	159	0.5	1.2	1.53	1.33	-2.48	37.9	-31.57
68	159	0.7	0.8	1.53	2.25	-7.04	51	-34.15
69	159	0.5	1	1.53	2.49	-7.92	42.6	-32.59
70	159	0.7	1.2	1.53	2.91	-9.28	76.3	-37.65
71	159	0.5	0.8	1.53	1.22	-1.73	40.7	-32.19
72	126	0.5	1	1	1.59	-4.03	55.2	-34.84
73	126	0.5	0.8	1.53	1.49	-3.46	40.1	-32.06
74	126	0.5	0.8	1	1.66	-4.40	50.3	-34.03
75	126	0.7	1	1	3	-9.54	54.4	-34.71
76	126	0.5	0.8	0.86	1.86	-5.39	50.6	-34.08
77	159	0.9	0.8	1	9.84	-19.86	62	-35.85
78	93	0.9	1.2	1.53	9.5	-19.55	55.6	-34.90
79	93	0.9	0.8	1.53	8.75	-18.84	44	-32.87
80	93	0.5	1.2	1.53	1.74	-4.81	42.2	-32.51
81	93	0.5	1	1	1.7	-4.61	46.3	-33.31

3.5 Analysis of Experimental Results

3.5.1 Analysis of Variance (ANOVA)

ANOVA was conducted to study the significant effects of experimental factors. This analysis was conducted using confidence level of 95 % at significant level of 0.05 (5 %). Table 7 and 8 shows the degree of freedom (DOF), sum of square (SS), mean square values (MS), f-value and percentage contribution (p) for surface roughness and cutting temperature (T).

The ANOVA for surface roughness shown in Table 7 shows a percentage error of 6.53 with feed rate (92.93 %) indicating the most significant parameter, followed by depth of cut (0.28 %) and cutting speed (0.13 %). Finally, the least significant factor is type of cutting fluids (0.12 %).

Table 7: ANOVA for surface roughness

Factors	DOF	SS	MS	F	P (%)
CS (rev/min)	2	**1.04**	0.52	0.727	0.13
FR (mm/rev)	2	733.07	366.6	512.76	92.93
DOC (mm)	2	2.218	1.109	1.5514	0.28
TCF (mm^2/s)	2	1.007	0.504	0.7044	0.13
Error	74	51.468	0.715		6.53
Total	80	788.80	9.860		100

Table 8: ANOVA for cutting temperature

Factors	DOF	SS	MS	F	P (%)
CS (rev/min)	2	1301.3	650.65	110.10	18.08
FR (mm/rev)	2	1980	990	167.5295	27.51
DOC (mm)	2	1611.2	805.6	136.3251	22.39
TCF (mm^2/s)	2	1867	933.5	157.9685	25.94
Error	74	437.23	5.909		6.08
Total	80	7196.8	89.96		100

Also, the ANOVA for cutting temperature shown in Table 8 shows a percentage error of 6.08 while feed rate (27.51 %) specifies the most significant parameter, followed by type of cutting fluid (25.94 %), depth of cut (22.39 %) and the least significant factor, type of cutting speed (18.08 %). The effects of all the factors are significant since their individual p-values are greater than 0.05%.

3.5.2 Empirical Model Equations

The empirical model equation for surface roughness and cutting temperature along with their respective Rsq values are shown in Equation 3 and 4.

$$Ra\ (\mu m) = -7.76 + 0.00024CS + 17.2FR + 0.95DOC + 0.034TCF \quad (3)$$

Rsq = 80.95% and Rsq (adj) = 79.95%

$$T\ (oC) = 20.13 + 0.0604\ CS - 21.79\ FR + 18.1\ DOC + 7.15\ TCF \quad (4)$$

Rsq = 61.85% and Rsq (adj) = 58.27%

The Rsq for cutting temperature shown in Equ. 4 is less than 80%. This may be due to noise which result from experimental uncertainty.

3.5.3 3D Surface Plots

The 3-D surface plot of surface roughness and cutting temperature are shown in Fig. 3 and 4. Fig. 3 and 4 shows how change in cutting speed and feed rate affects the surface roughness and cutting temperature when the depth of cut and cutting fluid are kept constant at 1 mm and 1.195 mm^2/s respectively. The plots also indicate that as cutting speed increases, feed rate also increases and vice versa.

3.6 Grey Relational Analysis (GRA)

As specified by [13], GRA optimization procedure involves calculating the grey relational generation (GRG) of individual responses using the S/N ratios values shown in Table 6. GRG was calculated using smaller-the-better attributes (x_{ij}) as shown in Equ. 5. This is followed by the conversion of GRG to grey relational coefficient (GRC) using Equ. 6. The final stage of GRA was the calculation of grey relational grade using Equ. 7. The results of GRA are shown in Table 9.

Smaller-the better,

$$(x_{ij}) = \frac{\overline{y}_{ij} - y_{ij}}{\overline{y}_j - \underline{y}_j} \quad (5)$$

(i = 1, 2, 3…. m and j = 1, 2, 3…. n)

Where, $y_i = (y_{i1}, y_{i2}, \ldots, y_{ij}, \ldots, y_{in})$, y_{ij} is the performance value of attribute j of alternative i and $\overline{y}_j = \max\{y_{ij}, i = 1, 2, \ldots, m\}$ and $\underline{y}_j = \min\{y_{ij}, i = 1, 2, \ldots, m\}$.

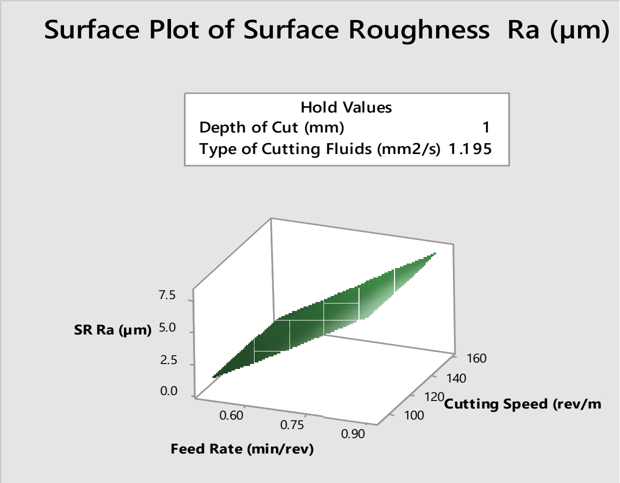

Fig. 3. 3D Surface plot for Surface Roughness

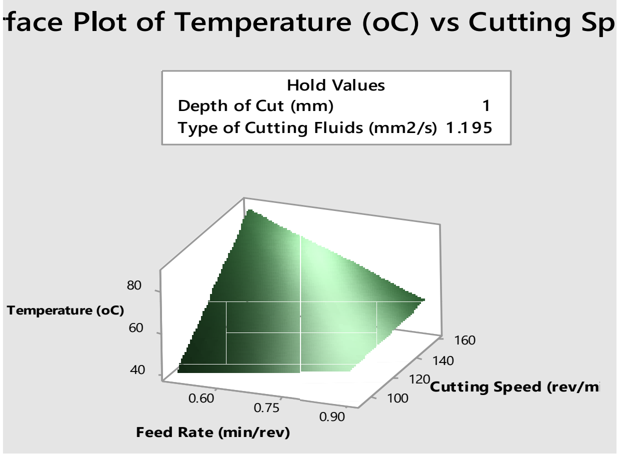

Fig. 4. 3D Surface plot for Temperature

$$\text{GRC, } \gamma(x_{0j}, x_{ij}) = \frac{\Delta_{\min} + \beta\Delta_{\max}}{\Delta_{ij} + \beta\Delta_{\max}} \quad (6)$$

(j = 1, 2, . . . , n and i = 1, 2, . . . , m)

$\Delta_{ij} = x_{0j} - x_{ij}$, $\Delta_{\min} = \min(\Delta_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$,

$\Delta_{\max} = \max(\Delta_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$ and β is the distinguishing coefficient, $\beta \in [0, 1]$. The aim of the distinguishing coefficient was to compress or expand the range of the grey relational coefficient and 0.5 is the widely accepted value [19].

$$\text{Grade, } \varphi\,(x_0, x_i) = \sum_{j=1}^{n} w_j \beta(x_{oj}, x_{ij}) \qquad (7)$$

(i = 1, 2, 3…….m); *wj* = weight of attribute *j*. $\sum_{j=1}^{n} w_j = 1$ [18].

The resulting factor effects of the process factors obtained using the grey relational grades as shown in Tables 9. The main effect plots obtained is as shown in Fig. 5.

Table 9: Results of Grey Relational Analysis

Sequence	Grey Relational Generation		Grey Relational Coefficient		Grade
	Ra	T(°C)	Ra	T(°C)	
1	1	1	0.333	0.340	0.337
2	0	0.03	0.806	0.375	0.591
3	0.88	0.17	0.945	0.380	0.663
4	0.97	0.18	0.507	0.361	0.434
5	0.51	0.11	1.000	0.394	0.697
6	1	0.23	0.891	0.382	0.636
7	0.94	0.19	0.393	0.361	0.377
8	0.23	0.12	0.727	0.365	0.546
9	0.81	0.13	0.512	0.338	0.425
10	0.52	0.02	0.444	0.370	0.407
11	0.38	0.15	0.404	0.364	0.384
12	0.26	0.13	0.446	0.346	0.396
13	0.38	0.06	0.883	0.362	0.622
14	0.93	0.12	0.400	0.383	0.392
15	0.25	0.19	0.467	0.349	0.408
16	0.43	0.07	0.709	0.374	0.541
17	0.79	0.16	0.440	0.348	0.394
18	0.36	0.06	0.408	0.375	0.392
19	0.28	0.17	0.404	0.362	0.383
20	0.26	0.12	0.896	0.342	0.619
21	0.94	0.04	0.423	0.366	0.394
22	0.32	0.13	0.838	0.418	0.628
23	0.9	0.3	0.894	0.341	0.618
24	0.94	0.03	0.474	0.396	0.435
25	0.45	0.24	0.805	0.378	0.592
26	0.88	0.18	0.431	0.377	0.404
27	0.34	0.17	0.907	0.430	0.669
28	0.95	0.34	0.371	0.372	0.372
29	0.15	0.16	0.457	0.381	0.419
30	0.41	0.19	0.776	0.356	0.566
31	0.86	0.1	0.498	0.352	0.425
32	0.5	0.08	0.487	0.383	0.435
33	0.47	0.19	0.456	0.379	0.418
34	0.4	0.18	0.877	0.367	0.622
35	0.93	0.14	0.373	0.339	0.356
36	0.16	0.02	0.405	0.347	0.376
37	0.26	0.06	0.374	0.358	0.366
38	0.16	0.1	0.990	0.406	0.698

Sequence	Grey Relational Generation		Grey Relational Coefficient		Grade
	Ra	T(°C)	Ra	T(°C)	
39	0.99	0.27	0.856	0.398	0.627
40	0.92	0.24	0.414	0.352	0.383
41	0.29	0.08	0.466	0.358	0.412
42	0.43	0.1	0.962	0.356	0.659
43	0.98	0.09	0.669	0.367	0.518
44	0.75	0.14	0.868	0.360	0.614
45	0.92	0.11	0.876	0.377	0.626
46	0.93	0.17	0.432	0.371	0.401
47	0.34	0.15	0.460	0.400	0.430
48	0.41	0.25	0.371	0.350	0.360
49	0.15	0.07	0.413	0.365	0.389
50	0.29	0.13	0.459	0.362	0.410
51	0.41	0.12	0.801	0.370	0.586
52	0.88	0.15	0.855	0.356	0.605
53	0.92	0.1	0.938	0.362	0.650
54	0.97	0.12	0.524	0.360	0.442
55	0.55	0.11	0.379	0.366	0.372
56	0.18	0.13	0.845	0.370	0.607
57	0.91	0.15	0.945	0.364	0.655
58	0.97	0.13	0.526	0.350	0.438
59	0.55	0.07	0.364	0.358	0.361
60	0.13	0.1	0.377	0.354	0.365
61	0.17	0.09	0.835	0.375	0.605
62	0.9	0.17	0.353	0.342	0.347
63	0.08	0.04	0.400	0.371	0.385
64	0.25	0.15	0.402	0.390	0.396
65	0.26	0.22	0.446	0.381	0.414
66	0.38	0.19	0.524	0.357	0.440
67	0.55	0.1	0.354	0.333	0.343
68	0.09	0	0.424	0.363	0.394
69	0.32	0.12	0.442	1.000	0.721
70	0.37	1	0.471	0.412	0.441
71	0.44	0.28	0.344	0.340	0.342
72	0.05	0.03	0.375	0.371	0.373
73	0.17	0.15	0.367	0.339	0.353
74	0.14	0.02	0.380	0.361	0.371
75	0.19	0.12	0.477	0.370	0.423
76	0.45	0.15	0.396	0.362	0.379
77	0.24	0.12	0.975	0.385	0.680
78	0.99	0.2	0.945	0.372	0.659
79	0.97	0.16	0.883	0.347	0.615
80	0.93	0.06	0.387	0.343	0.365
81	0.21	0.04	0.383	0.352	0.368

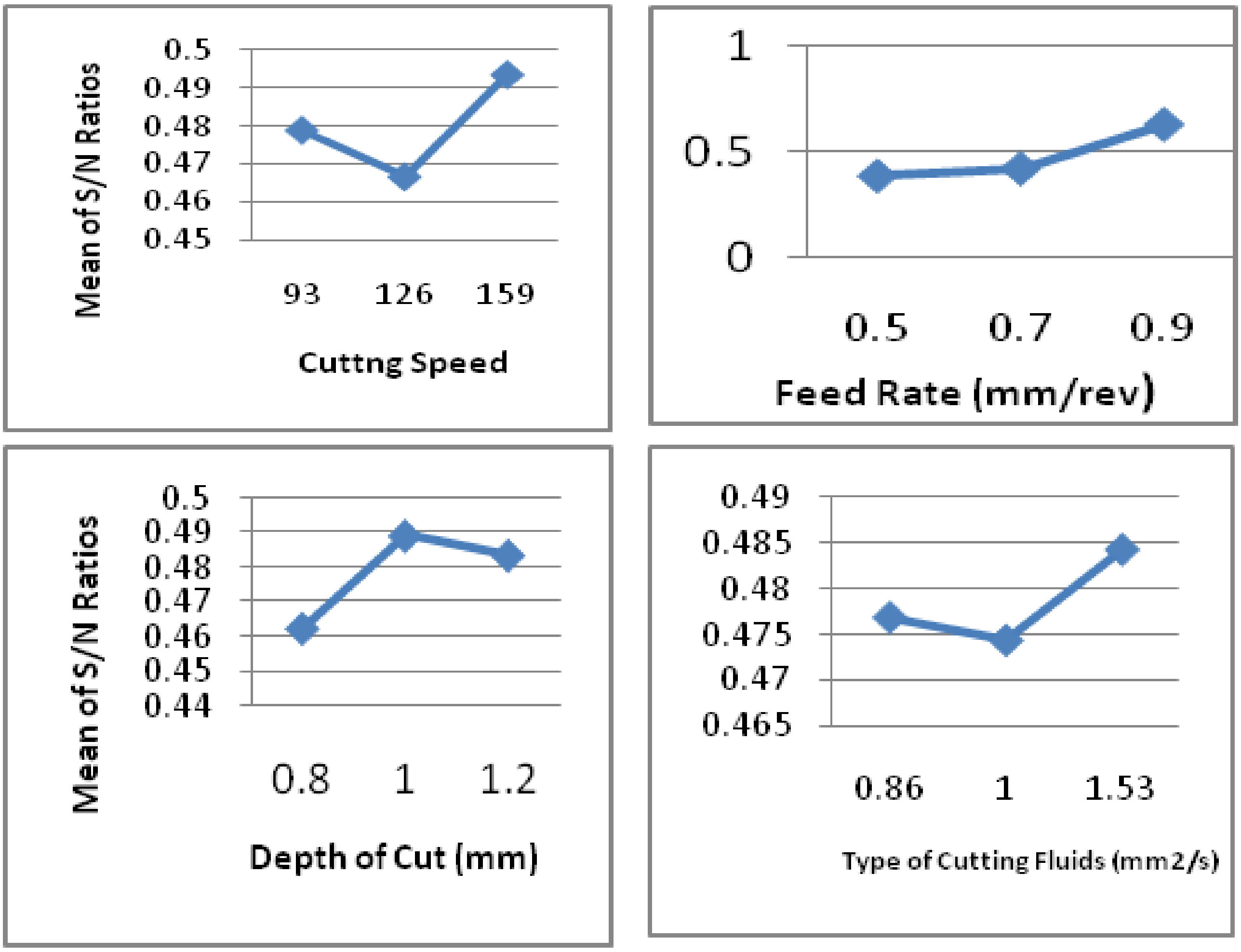

Figure 5. Plots of Factor Effects

The main effect plots shown in Fig. 5 indicates that optimum multi-response machining performance can be achieved using cutting speed of 159 m/s, feed rate of 0.9 mm/rev, cutting depth of 1 mm as well as a commercially available mineral oil of 1.53 mm^2/s viscosity. Any change in these optimal parameters may lead to poor performance of the turning process.

4. CONCLUSIONS

The properties of melon seed and beniseed oils were investigated and the performance evaluation of these oil-based cutting fluids involving the formulation of beniseed and melon seed oil cutting fluids have been carried out. The formulated oil cutting fluids were used in turning AISI 304L alloy steel using a tungsten carbide cutting tool and compared with commercial mineral oil- based cutting fluid. The performance evaluation of formulated cutting fluids was investigated by determining its surface roughness and cutting temperature. The following conclusions were drawn:

i. The viscosities of the melon seed oil and beniseed oil based cutting fluids were 1.53mm$^{2/s}$ and 0.86mm$^{2/}$s, while their pH values were 8.2 and 8.7 respectively.

ii. The fatty acid composition of the melon seed and beniseed oil influenced the pH levels and viscosities of their respective cutting fluid, which also affected their performances during machining of AISI 304L alloy steel, using tungsten carbide cutting tool.

iii. The optimal multi-response turning parameters was achieved using cutting speed of 159 rev/min (level 3), feed rate of 0.9 mm/rev (level 3), depth of cut of 1 mm (level 2) and type of cutting fluid of 1.53mm/s (level 3).

iv. Also, the ANOVA results show that feed rate has most significant effect on the surface roughness and cutting temperature.

5. REFERENCES

[1] Sahu, M. K., Verma, M., & Khandelwal A. K. Experimental Investigation of Machining Parameter in Turning Operation Using Full

Factorial Design. *Journal of Harmonized Research in Engineering*. 2(2), 2014. Pp 301 – 316. ISSN 2347 – 7393.

[2] Kawi, A. A. Temperatures Behaviour of Some Alloy Steel in Turning Process Under Different Operating Conditions. *Al-Qadisiya Journal for Engineering Sciences*. Volume 4, No. 3 of 2011

[3] Thamizhmanii, S., Sapurudin, S., & Hasan, S., Analysis of Surface Roughness by Turning Process Using Taguchi Method. *Journal of Achievements in Materials and Manufacturing Engineering.* Vol. 20, Issues 1-2, January-February, 2007. PP. 503-506

[4] Rajesh, C. Tune – In Optimization Processes of AISI 4140 in Raw Turning Operation Using CVD Coated Insert. *International Journal of Advances in Engineering and Technology.* July, 2014, Volume 7, Issue 3, pp. 980-990

[5] Weinert, K., Inasaka, I., Sutherland, J. W., & Wakabayashi, T. Dry Machining and Minimum Quantity Lubrication. *CIRP Annals – Manufacturing Technology.* Volume 53, No.2, 2004, pp 511-537.

[6] Sharif, S., Yusof, N. M., Idris, M. H., Ahmad, Z. A., Sudin, I., Ripin, A., & Zin, A. H. M.. Feasibility Study of Using Vegetable Oil as a Cutting Lubricant Through The Use of Minimum Quantity Lubrication During Machining. *Research Vot No: 78055*. Department of Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia., 2009.

[7] Hill, K. Fats and Oils as Oleochemical Raw Materials. *Pure and Applied Chemistry.* Volume 72. 2000. PP 1255-1264,

[8] Hwang Y.K., & Lee C.M., Surface Roughness and Cutting Force Prediction in MQL and Wet Turning Process of Process of AISI 1045 Using Design of Experiment. *Journal of Mechanical Science and Technology.* **24** (8) 2010. pp 1669-1677.

[9] Lawal, S. A., Choudhury, I .A., & Nukman, Y. Experimental Evaluation and Optimization of Flank Wear During Turning of AISI 4340 Steel with Coated Carbide Inserts Using Different Cutting Fluids. *Journal of the Institution of Engineers India: Series C. Mechanical, Production, Aerospace and Marine Engineering.* 96, (1), 2014, pp. 21-28**.**

[10] Bajić, D., & Majce, I. (2006). Optimisation of Parameters of Turning Process. *International Scientific Conference on Production Engineering.* (June-July, 2006). Zagreb Lumbarda, Hrvatska. pp 129-136.

[11] Onuoha, O. J, Suitability of Vegetable Based oils in Orthogonal Machining of AISI 1330 Carbon Steel Using Taguchi Method. Unpublished PhD Thesis submitted to the Mechanical Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, Nigeria.

[12] Yu, Y., Guo, Y., Wang, L., & Tang, E. Development of Environmentally Friendly Water-Based Synthetic Metal-Cutting Fluid. *Modern Applied Science*. Volume 4, No. 1, January, 2010. pp 53-58.

[13] Yiyo, K., Taho,Y.& Guan, W. H. The use of a grey-based Taguchi method for optimizing multi-response simulation problems. *Engineering Optimization,* 40(6), 517–52.

[14] Muniz, C. A. S., Dantas, T. N. C., Moura, E.F., Neto, A. A. D., & Gurgel, A. Novel Formulations of Cutting Fluids using Naphtenic Basic Oil. *Brazilian Journal of Petroleum and Gas.* Volume 2, No.4, pp. 143-153, 2008.

[15] Alves, S. M., & Oliveira, J. F. G. Vegetable Based Cutting Fluid – An Environmental Alternative to Grinding Process. 15th CIPR International Conference on Life cycle Engineering, 2008.

[16] Sunday Albert Lawal; Imtiaz Ahmed Choudhury and Yusoff Nukman. Evaluation of vegetable and mineral oil-in-water emulsion cutting fluids in turning AISI 4340 steel with coated carbide tools. *Journal of Cleaner Production*, 66, 610 – 618.

[17] Godfrey, D., & Herguth, H. R. Back to Basics; Physical and Chemical Properties of Industrial Mineral Oils Affecting Lubrication. Part 1-5. Society of Tribologists and Lubrication Engineers, Illinois. 1995. Available: http://www.stle.org/ of 17 August, 2016.

[18] Oseni, M. I., Agbi, B. E., and Ogamenyi, I. O. Extraction and Analysis of Chemo-physical Properties of Yellow Oleander Oil as Lubricant. *British Journal of Applied Science & Technology*. 4 (**6**), pp 1020-1029, 2014.

[19] Chin, P. F. Manufacturing process optimization for wear property of fiber-reinforced polybutylene terephthalate composites with grey relational analysis, *Wear,* 254, 298–306, 2003.